Tunable Narrowband Semiconductor Reference Oscillator Technology for Coherent Detection Lidar

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ABSTRACT

Semiconductor laser reference oscillators offer reduced mechanical complexity and improved frequency agility over equivalent crystal laser devices, while their potentially faster tuning capability offers greater scanning versatility. We report on a program to fabricate prototype of novel architecture semiconductor lasers with the power and spectral characteristics required for coherent Doppler lidar.

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Introduction

The coherent Doppler lidar approach for acquiring global profilometry of tropospheric winds from Earth orbit is reliant on off-nadir beam scanning geometry for retrieval of vector winds by Doppler analysis of laser radiation backscattered by entrained aerosols and cloud particles (Baker *et al.*, 1995). The off-nadir scan pattern induces large platform-induced Doppler components that may be compensated by scan-synchronous tuning of a frequency-agile local oscillator (LO) laser. Frequency-agile LO technology development has thus far implicitly assumed the same laser material as the transmitter laser. (The currently favored spectral region for conducting Doppler lidar wind sounding is ~2.05 μm, the operating wavelength of Tm,Ho:YLF.)

This approach has been under development for a number of years and has demonstrated functionality in a breadboard system close to that required for the space-based implementation (McGuckin and Menzies, 1992; McGuckin *et al.*, 1993; Hemmati *et al.*, 1998). However, compared to diode laser technology such devices are mechanically complex, with tuning stability and reproducibility being critically dependent on the maintenance of stringent alignment tolerances. An alternative monolithic semiconductor laser reference oscillator would offer superior resistance to environmentally induced alignment degradation and generally longer lifetime. In addition, the semiconductor laser option has the potential for considerably more rapid tuning capability, rendering feasible a wider variety of lidar pointing/scanning strategies.

The fabrication and validation of prototype novèl architecture semiconductor lasers is presently under way at the Jet Propulsion Laboratory (JPL) with the express goal of addressing the power and spectral purity requirements of spacebased coherent Doppler lidar wind measurement and laser absorption spectrometry for global CO_2 mapping (Menzies *et al.*, these proceedings).

Laser Materials

Risk reduction considerations led to the establishment of a parallel development program involving two candidate laser material systems:

Indium Phosphide (InP) Material System

Indium phosphide and its alloys indium gallium arsenide phosphide (InGaAsP) are well developed for fabrication of semiconductor lasers in the 1.3-1.55 μm wavelength region for light transmission through fiber optics in telecommunication applications. All the fabrication technologies, including the epitaxial growth and re-growth conditions for producing reliable, high performance single mode operation are well known and routinely used. It has already been demonstrated that wavelengths as long as 2.06 μm can be achieved in the InGaAsP/InP material system using highly strained InGaAs quantum wells with lattice matched InGaAs barriers (Forouhar *et al.*, 1993). Sensors based on tunable diode lasers of the latter type with emission in the 2.04-2.05 μm region have been produced at JPL for the detection of carbon dioxide and its isotopes in the Martian atmosphere.

Although InGaAsP single-mode distributed feedback (DFB) lasers at 2.06 μm have already been demonstrated, the maximum output power of the lasers was limited to ~2 mW and the linewidths were >>10 MHz, well in excess of the <1 MHz required for the wind measurement application. In order to drive the photomixer in a heterodyne receiver configuration into the desired shot-noise limited regime the LO source should ideally be capable of delivering 20-mW output in order to compensate for losses within the optical train.

The InGaAsP material system was identified as a candidate for this application several years ago (Menzies *et al.*, 1997). However, thus far the output power levels achieved are inadequate for the current application. Several options are under investigation for extending the power output of these devices to the required levels.

Gallium Antimonide (GaSb) Material System

The gallium antimonide materials and lasers based on this material system for emission in the 2-5 μm range are being actively researched for chemical sensing and chem/bio countermeasures applications. Considerable progress has been made in research on mid-infrared gallium antimonide-based lasers in terms of their maximum operating temperature and output power. A major breakthrough was achieved in 1992 (Choi and Eglash) by employing InGaAsSb/AlGaAsSb strained quantum well structures. The resulting lasers operated at 2.15 μm and had room temperature threshold current densities as low as 260 A/cm^2, while more recently a 2.05-μm laser with 50 A/cm^2 threshold current density has been demonstrated (Bleuel *et al.*, 1999).

Wavelength and Linewidth Control Issues

Gratings with spatial periodicity designed to match a particular optical wavelength are most often used for wavelength control and single mode selection in semiconductor lasers. The distributed feedback laser (DFB) uses gratings etched into the waveguide layers along the whole length of the cavity. Another design, the distributed Bragg reflector laser (DBR), uses gratings in passive waveguide sections at the end of the cavity, which may be monolithically integrated or in a separate chip for hybrid integration.

Assuming single mode operation, the linewidth of a semiconductor laser is given by the modified Schawlow-Townes formula, where P is the optical power emitted, n_{sp} is the ratio of the upper and lower band population densities, τ_p is the photon lifetime, and α is the linewidth enhancement factor (Henry, 1982):

$$\Delta \nu = \frac{h\nu}{2P\tau_p} n_{sp}(1+\alpha^2) \quad .$$

Typical semiconductor DFB lasers at near-IR wavelengths have linewidths of ~1-2 MHz. At high currents and powers, standard DFB lasers suffer from re-broadening effects, which cause the linewidth to remain constant or even increase with output power. Below 1 MHz linewidth, special grating designs are necessary such as the corrugation pitch-modulated (CPM) laser (Okai, 1994) which utilizes detuned central sections to prevent intensity peaking in the center of the cavity (Figure 1).

Prototype Laser Performance

Performance optimization of multi-quantum well (MQW) compressively strained laser structures based on InGaAs/InP have been investigated for the development and fabrication of narrow linewidth lasers in the 2-μm spectral region. The laser wafers were prepared by atmospheric pressure metal-organic vapor phase epitaxy on [100] oriented n-InP substrate. The structure consists of two quantum wells of $In_{.75}Ga_{.25}As$ each 11 nm wide, separated by 20 nm of InGaAsP (with composition corresponding to a band gap wavelength of 1.3 μm). InP was used in the cladding layers. 3-μm wide ridge waveguide Fabry-Pérot (FP) lasers were fabricated to evaluate the performance of the lasers.

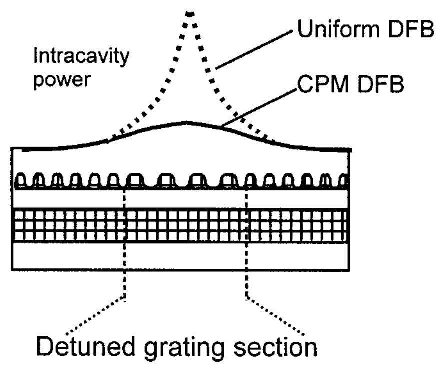

Figure 1. Central detuned grating section in a CPM laser prevents build-up of intensity that causes linewidth re-broadening.

Several lasers were tested in the bar form in the pulsed (5 μs, 1 kHz) and continuous (cw) modes of operation at a constant temperature of 15°C. The light vs. current characteristics for a 1.5-mm long laser are shown in Figure 2.

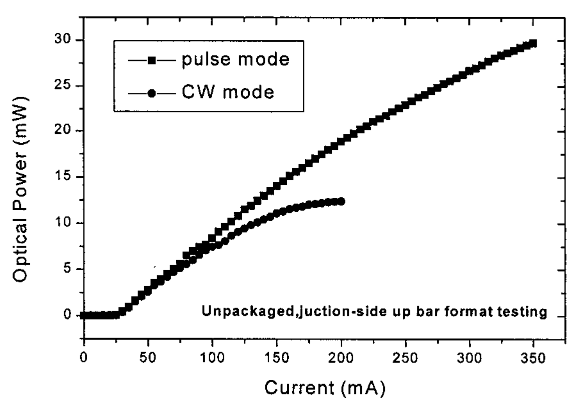

Figure 2. Pulsed and cw output power as a function of current for a bar format un-packaged and junction-side up, 3-μm ridge waveguide, 1.5-mm long FP laser.

Most of the 1.5-mm long lasers have a threshold current as low as ~25 mA and external efficiency greater than 30%. Laser operation was observed up to 50°C. The peak optical powers observed are ~29 mW in the pulsed mode and ~12 mW in the continuous mode of operation. These measurements are for the tested laser chips in the bar form; we expect higher output powers when these lasers are appropriately packaged. These optical power levels are among the highest power levels reported for lasers based on InGaAs/InP at these wavelengths. Previously reported results (Forouhar *et al.*, 1993) for similar based structure with 5-μm ridge waveguide, 1-mm cavity length FP lasers exhibited only ~5 mW of optical power in the cw mode of operation. The emission spectrum of a 1.5-mm long cavity laser is shown in Figure 3 with the peak wavelength at 1.990 μm.

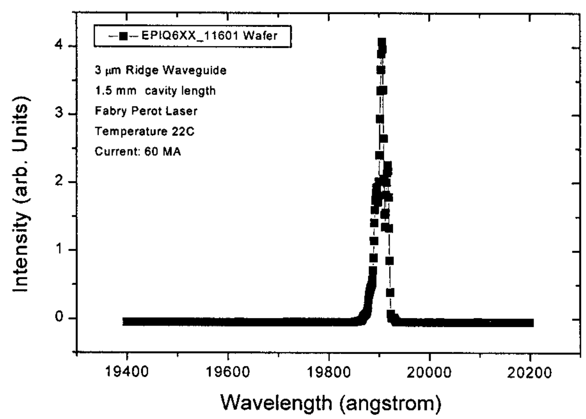

Figure 3. Laser emission spectrum for 3-μm ridge waveguide, 1.5-mm long cavity length FP laser in pulsed mode of operation.

With further optimization of the well and barrier thicknesses, compressive strain, and composition we have also been able to extend the emission wavelength. Figure 4 shows the photo-luminescence of one such base structure, where the centroid wavelength is around 2.054 μm.

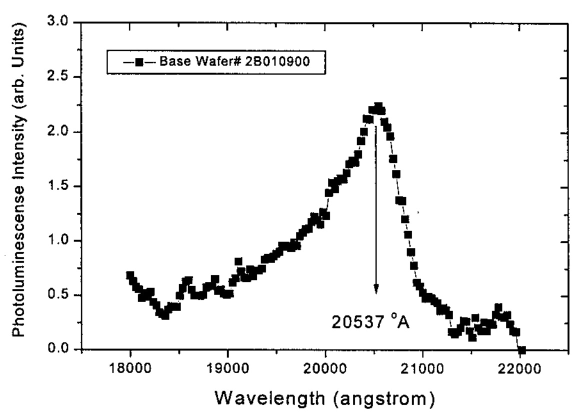

Figure 4. Photoluminescence spectrum of InGaAs/InP wafer.

We anticipate the availability of CPM-DFB structures in these materials in the near future in order to fully address the linewidth target for the Doppler wind lidar application.

Acknowledgments

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